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Final Report
June 1, 1997 thru November 30, 2000

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Award Number: F49620-97-1-0428

Title: Directionality of Magnetic Properties in Fe-Co Alloys

A program was written to analyze the data following the general outline of Nye's analysis of anisotropic properties but adapted to the symmetries appropriate to magnetostriction in cubic materials such as the bcc Fe-Co alloy under study. The results of the analysis revealed, however, that the calculated coefficients of the magnetostriction tensor were too small and exhibited large errors. Moreover, the field strengths applied were only a few Gauss, after accounting for demagnetization effects, whereas the field strength required to saturate the magnetostriction strain is of the order of one hundred Gauss, far above the capabilities of the apparatus available to the project at the time. Our conclusion was, therefore, that a new approach will be required in order to perform the experiment as originally designed. The challenge will be to find a way to apply high magnetic fields in a conformation that permits the laser illumination to be reflected off the sample surface at angles far from normal incidence.

4. ACCOMPLISHMENTS, FINDINGS

The major finding from the project was that the precision of the method was not sufficient to extract meaningful results. The combination of (small) sample size and limited spatial resolution in displacement measurement resulted in a very low signal-to-noise ratio. It is possible that if the sample size could be increased to be a centimeter or larger, and also if significant (and expensive) upgrades could be made to the optical components in the laser speckle interferometer, it might be feasible to measure the magnetostriction tensor.

An additional finding was that strong textures occur in rolled Hiperco-50 sheet that explained the anisotropy observed in the mechanical properties.

5. PERSONNEL SUPPORTED: The project supported a graduate student, Mr. Mark Storch.

6. PUBLICATIONS:

"Approach to Saturation in Textured Soft Magnetic Materials," A. D. Rollett, M. L. Storch, E. J. Hilinski and S. R. Goodman, *Metallurgical & Materials Transactions*, **32A** (10), 2595-2603A (2001).

"The effect of mechanical working on the in-plane magnetic properties of Hiperco 50", M. L. Storch, A. D. Rollett and M. E. McHenry, *J. Applied Physics*, **85** (8), 6040-6042 Part 2B (1999).

"Texture and Microstructure Gradients in a Cold Rolled Electrical Steel", M. L. Storch, A. D. Rollett, J. Floder, P. S. Lee, M. E. McHenry and S. R. Goodman, Proc. 40th Mechanical Working and Steel Processing, Pittsburgh, October, 1998, p. 513.

"Sensitivity of Magnetic Permeability to Texture and Microstructure in a Cold Rolled Electrical Steel," A. D. Rollett, J. Floder, P. S. Lee, M. E. McHenry, M. L. Storch and S. R. Goodman, in *Textures in Materials Research*, Proc. NASAT-97, National Seminar on

2. TECHNICAL OBJECTIVE

The objective of the proposed research was to develop quantitative relationships between the texture (crystallographic preferred orientation) of Fe-Co alloys and the directionality of their magnetic properties. The processing history of the alloys was varied in order to obtain a variety of textures and therefore magnetic properties. Physically based models were used to make correlations between texture and magnetic properties. An attempt was made to determine both the optimum magnetic properties (for general application in rotating electrical machinery) and the optimum processing route.

3. STATUS OF EFFORT: SUMMARY OF WORK UNDERTAKEN

The project ended in 2000. The graduate student who was supported on this project, Mark Storch, continued the work under alternative support until August 2001. He then elected to leave the doctoral program with a Masters degree only and pursue other interests. Technical results are reported in the next section.

This project started with an investigation of texture and its relation to mechanical and magnetic anisotropy in the Fe-Co-V alloy supplied by an industrial partner (Carpenter). Texture was measured via x-ray diffraction pole figures and analyzed in terms of the orientation distribution function (ODF). Good agreement was found between the mechanical anisotropy predicted from the crystallographic texture and the experimental results. The agreement between the experimentally measured magnetic anisotropy (torque magnetometry) and the anisotropy predicted from the crystallographic texture, based solely on magnetocrystalline anisotropy, was less good. The discrepancies prompted a re-examination of the basis for the anisotropy as it became apparent that magnetostriction was playing a more important role than previously understood.

In order to investigate the magnetostrictive properties of the Fe-Co alloy, a new experiment was undertaken based on the suggestions of Dr. Fred Rothwarf. A laser speckle interferometer was purchased and installed at CMU. This instrument is designed for measurement of displacements on a surface and has the advantage that it can measure displacements in all three dimensions. With a few important but reasonable assumptions, it is then possible to calculate the full strain matrix from the measured displacement fields. The objective of this approach was to apply a completely new method for measuring magnetostriction without any assumptions about the symmetry of the phenomenon. Previous measurements of magnetostriction have almost all relied on strain gauges that provide less complete information on material deformation.

The apparatus was configured with orthogonal solenoidal coils to apply magnetic fields in arbitrary directions while measuring the resulting magnetostrictive strains in a sample placed in the field. A sample of the Fe-Co alloy taken from a coarse-grained casting was annealed for very long times in order to generate grain sizes greater than a few millimeters. From this sample, individual crystals were cut and oriented with the aid of Laue diffractometry. A series of fields of varying orientation and strength were applied to a set of six different orientations (of single crystals) in order to characterize the anisotropy of magnetostriction.

Texture (Hyderabad, India, December 1997) , Oxford & IBH Publishing Co., New Delhi, India, p. 235.

7. INTERACTIONS/TRANSITIONS

The external interactions were focused on two partners, Rick Fingers at the Wright Patterson Air Force Base (Propulsion Group), and Scott Masteller at Carpenter Steel company. Scott Masteller was an invaluable source of materials, information and advice on the program. Rick Fingers was involved in the More Electric Aircraft Program in the area of mechanical properties. He supplied texture data which the PI analyzed and produced an informal report (June, 1997) on anisotropy in Hiperco and Telcon Fe-Co alloy foils. The interactions were productive on both sides.

8. NEW DISCOVERIES: N/A

9. HONORS/AWARDS: N/A

10. SUMMARY

In summary, significant progress has been made towards making quantitative links between magnetic anisotropy and microstructure, as expressed by quantitative texture measurement. The method of laser speckle interferometry was applied to the problem of measuring the magnetostriction tensor in Fe-Co alloys. The method has the potential to provide more complete information on magnetostrictive behavior than traditional methods. Significant re-design of the experimental apparatus will be required, however, before useful results can be obtained.